9950-638

DRL. No. 74/DRD No. SE
Line Item No. 7

DOE/JPL-955089 81/12
Distribution Category UC-63

SILICON SOLAR CELL PROCESS DEVELOPMENT, FABRICATION, AND ANALYSIS

TENTH QUARTERLY REPORT

FOR PERIOD COVERING

1 JULY 1981 TO 30 SEPTEMBER 1981

H.I. Yoo, P.A. Iles, and D.C. Leung

JPL CONTRACT NO. 955089

OPTICAL COATING LABORATORY, INC.
Photoelectronics Division
15251 E. Don Julian Road
City of Industry, California 91746

"The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Government of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE."

(NASA-CR-168670) SILICON SOLAR CELL PROCESS DEVELOPMENT, FABRICATION, AND ANALYSIS Quarterly Report, 1 Jul. - 30 Sep. 1981 (Optical Coating Lab., Inc., City of) 61 p HC A04/MF A01 CSCL 10A G3/44

N82-20650

Unclas
09327

DRL. No. 74/DRD No. SE
Line Item No. 7

DOE/JPL-955089 81/12
Distribution Category UC-63

SILICON SOLAR CELL PROCESS

DEVELOPMENT, FABRICATION, AND ANALYSIS

TENTH QUARTERLY REPORT

FOR PERIOD COVERING

1 JULY 1981 TO 30 SEPTEMBER 1981

H.I. Yoo, P.A. Iles, and D.C. Leung

JPL CONTRACT NO. 955089

OPTICAL COATING LABORATORY, INC.
Photoelectronics Division
15251 E. Don Julian Road
City of Industry, California 91746

"The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Government of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE."

ABSTRACT

During this reporting period, work has progressed in fabrication and characterization of solar cells from UCP wafers and LASS ribbons. Gettering tests applied to UCP wafers made little change on their performance compared with corresponding baseline data. Advanced processes such as SJ, BSF, and MLAR were also applied. While BSF by Al paste had shunting problems, cells with SJ and BSF by evaporated Al, and MLAR did achieve 14.1% AM1 on UCP silicon..

The study of LASS material was very preliminary. Only a few cells with SJ, BSR, (no BSF) and MLAR were completed due to mechanical yield problems after lapping the material. Average efficiency was 10.7% AM1 with 13.4% AM1 for CZ controls. Relatively high minority carrier diffusion lengths were obtained. The lower than expected Jsc could be partially explained by low a^tive area due to irregular sizes.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

The objective of this program is to investigate, develop, and utilize technologies appropriate and necessary for improving the efficiency of solar cells made from various unconventional silicon sheets. During the reporting period, work included fabrication and evaluation of solar cells from UCP (SEMIX) material and LASS ribbons (Energy Material). Attempts were made to getter some UCP wafers. In addition, advanced processes such as shallow junction (SJ) which is always accompanied with narrow close spaced grid lines, back surface field (BSF) or back surface reflector (BSR), and multi-layer AR coating (MLAR) were applied to selected samples of UCP or horizontal ribbon silicon. The results from UCP cells were compared to the baseline processed cells. Also some effort was made to study material properties of UCP silicon.

II. TECHNICAL DISCUSSION

A. Solar Cells From Cast Ingot By Ubiquitous Crystalline Process (UCP)

1.0 Baseline Solar Cell Fabrication

Six (6) polycrystalline UCP wafers (10x10cm) representing six (6) different groups of material were delivered. Each wafer was polished and cut to 2x2cm blanks with their position marked (see Figure 1 for the positions). With the orientation of each wafer and its position in each group of material known, one can use the results of the cell performance to correlate with the properties of each material group.

All wafers were polycrystalline with mm size grains. Measured resistivity was about 3 ohm-cm. A baseline process was applied to fabricate solar cells. Refer to reference (1) for the details of UCP process; reference (2) details the baseline process.

2.0 Solar Cell Performance and Characterization

Characteristics Under Illumination

Solar cell parameters, such as Jsc, Voc, CFF, and η were measured under AM1 conditions at 28°C test block temperature. The results of the cells are summarized in Table 1 and all the parameters are listed in Appendix III. One can see from the Table that the cell performance was relatively uniform. The few cells which had shunting problems showed inclusions under microscope observation. Figure 2 shows microscopic pictures of the inclusions observed in a cell which showed severe shunting problems.

Analysis of data and visual observation indicated that the variation of Jsc was related to the grain size of the material and the average Jsc was lower than the

CZ control by more than 11%. The lower Voc could be partly accounted for by slightly higher resistivity of the material (~3ohm-cm) than the CZ control (~1 ohm-cm). The average efficiency was considerably lower than the CZ control; 10.6% versus 13.1%.

Spectral Response

Absolute spectral response (A/W) was measured using the filter wheel setup. (See Reference 2 for details.) Plots of the response of representative cells without AR coating are given in Figure 3. The UCP cells gave lower response than the CZ control cell, especially at long wavelength (~0.6um), suggesting reduced minority carrier diffusion length.

Minority Carrier Diffusion Length

Effective minority carrier diffusion length (L_D) was obtained using the short circuit current method (see Reference 2 for details) of the finished solar cells. Results from selected samples are summarized in Table 2 in which short circuit current density information is given in right hand column for reference. The table indicates a range L_D of around 20-70um.

Photoresponse By Small Light Spot Scanning

Localized photoresponse of the UCP solar cells was obtained by light scanning. (Refer to Appendix of Reference (1) for details of the measurement.) Typical scanning results are given in Figures 4 and 5. Figure 4 represents scanning of a cell which is relatively free from grain boundaries, and Figure 5, response of a cell with small grain structure. The cell with smaller grains showed reduced response, and wide spatial variations. Photoresponse of the CZ control cells are shown.

The above two sections were reproduced from the Annual Report (Phase III) for ease of reference.

The figures indicate that response in the bulk of the UCP cell is lower than the CZ controls.

3.0 Gettering Test

The gettering process used was to polish the wafer, $POCl_3$ diffusion at 875°C for 30 minutes, and etch by 2:15:5 (HF-HNO_3-CH_3COOH) to remove the junction. After the gettered layers were removed, the baseline process was used to make 2x2cm cells. (The baseline process involved conservative diffusion, grids with 91% active area, and SiO AR coating.) Solar cell parameters (Isc, Voc, CFF, and η) were measured under AM1 at 28°C test block temperature.

Table 3 summarizes the results of the gettering test. (All parameters are listed in Appendix III.) On comparing with Table 1, no increase in output can be seen as a result of the gettering. The cells made from corresponding slices (D,E, etc.) were fairly close for both tests

4.0 High Efficiency Processes

A total of four attempts were made to fabricate high efficiency cells from the UCP material. The first two attempts were made with SJ, BSF by aluminum paste and MLAR. The third attempt was made with SJ, BSR (no BSF), and MLAR, and the fourth was made with SJ, BSF by evaporated Al and MLAR. (See Reference (2) for description of the processes.) For the evaporated Al BSF, a (2um) Al layer was evaporated and was alloyed for 15 minutes at 800°C. Parallel baseline solar cells were fabricated, for the second attempt because it used new

wafers without previous baseline performance. The other tests were performed on material with baseline results reported in Table 1.

Tables 4-7 summarize the results for the four attempts while Table 8 shows the parallel baseline solar cells for the second attempt. All the detailed parameters are listed in Appendix III.

The results of Al paste by BSF as shown in Table 4 and 5 were very disappointing. There were many shunting problems as reflected in the low CFF. For those cells with reasonable CFF, there were no observable improvement of Voc as compared with baseline results (Table 1 of and Table 8.) Shunting problems in Al paste by BSF have been often observed in the past. It was believed to be caused by incomplete alloying of Al in the back surface and sometime Al contamination on the front. The physical causes of such effects are not fully understood. A recent attempt by Cilik and Katz of SEMIX (Reference 3) to explain it by a model of parallel junction P/N^{+} in the back surface for areas that fail to alloy, cannot be applied in this case, for there was no N^{+} in the back surface which was protected by a layer of CVD oxide during diffusion. Also notice that the shunting in the control cell in the second attempt (Table 5) was much less than the UCP material. This suggests a material-related problem. In these two attempts the best UCP Si cell was 13.2% AM1. The expected increase of Jsc from SJ and MLAR was mainly responsible for the increase here. In order to by-pass the BSF problem, two approaches were attempted. First, cells were fabricated with an evaporated BSR only. Table 6 shows that there was reduced shunting. The other approach used a 2um evaporated Al layer alloyed to form BSF. The results are summarized in Table 7. As expected, this BSF method did not have severe shunting problems associated with Al paste BSF method. Also an

increase of Voc was detected. The highest Voc of 584 mV is at least 10mV higher than any previous Voc value on UCP silicon. The highest AM1 η value was 14.1% and is the highest value for UCP silicon to date in these tests.

Spectral Response

Absolute spectral response (A/W) measurements were made using a filter wheel set-up. Response versus wavelength of selected cells are given in Figure 6 and Figure 7. One can see that both the blue and red responses of BSR cells (Figure 6) is lower than the evaporated Al BSF cells (Figure 7). This is not only a BSF effect since the BSF does not affect blue response, but most likely is caused by less effective MLAR coating.

5.0 Correlation With SEMIX Work

Two reports (Reference 4 and 5) describe SEMIX processed cells on UCP Si. The Table 1.1 of Reference 4 is reproduced; it shows the results from 2x2 cm cells on an early brick of UCP Si. These results, which used a cell process somewhere between ASEC baseline and high efficiency processes, are similar to the results quoted above (Table 1 and 7).

In a later report, using similar processing for thousands of large area cells ($92cm^2$), gave average η values between 8.93 and 10.09% (Table 2.1 in Reference 5).

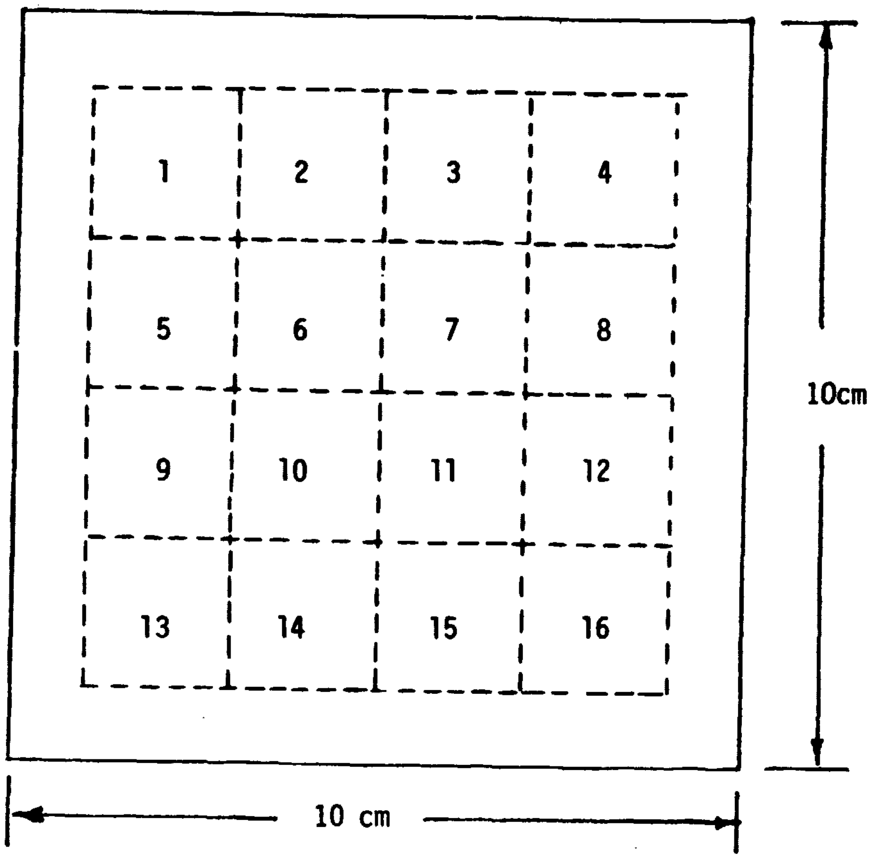
6.0 Material Study On UCP Si

It was mentioned earily that the small variation of Jsc was related to the grain size of the material (Section 2.0). In order to understand the effects of the grain boundaries on the performance of the cells, an EBIC study was carried out on

selected cells by JPL. Figure 8A was the result of EBIC on cell D-1-1 (by S. Hyland of JPL). Figure 8B was the actual picture of grain boundary of wafer D-7 which is from the same portion of the crystal and the enclosed region corresponds to the area in Figure 8A. One can see there exists a correspondence between the grain boundary and the dark lines of the EBIC. These indicate that many of the grain boundaries are electrically active, and would have an influence on the lifetime of the material. More detailed study is needed to further our knowledge of the relationship between material properties and solar cell performance of the UCP material.

FIGURE 1.

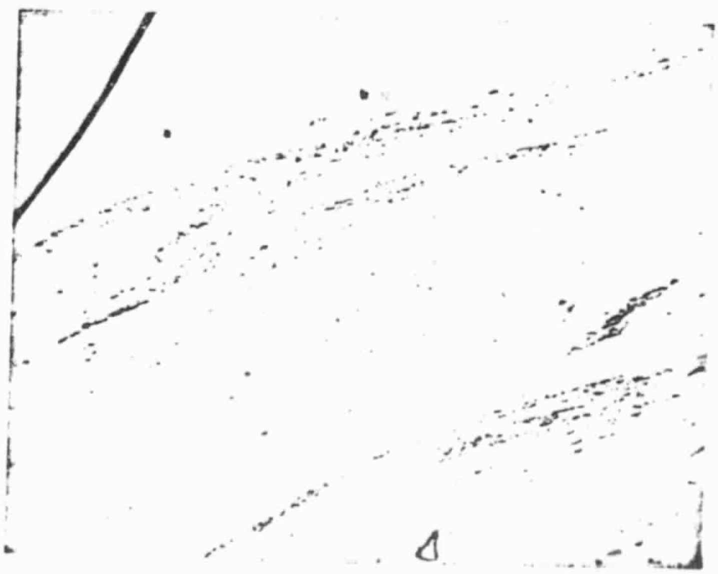
MAPPING OF THE 2 X 2 CELLS IN SEMIX WAFER



Shown here are the cells' number and their positions with the orientation of the wafer pre-determined.

ORIGINAL PAGE IS
OF POOR QUALITY

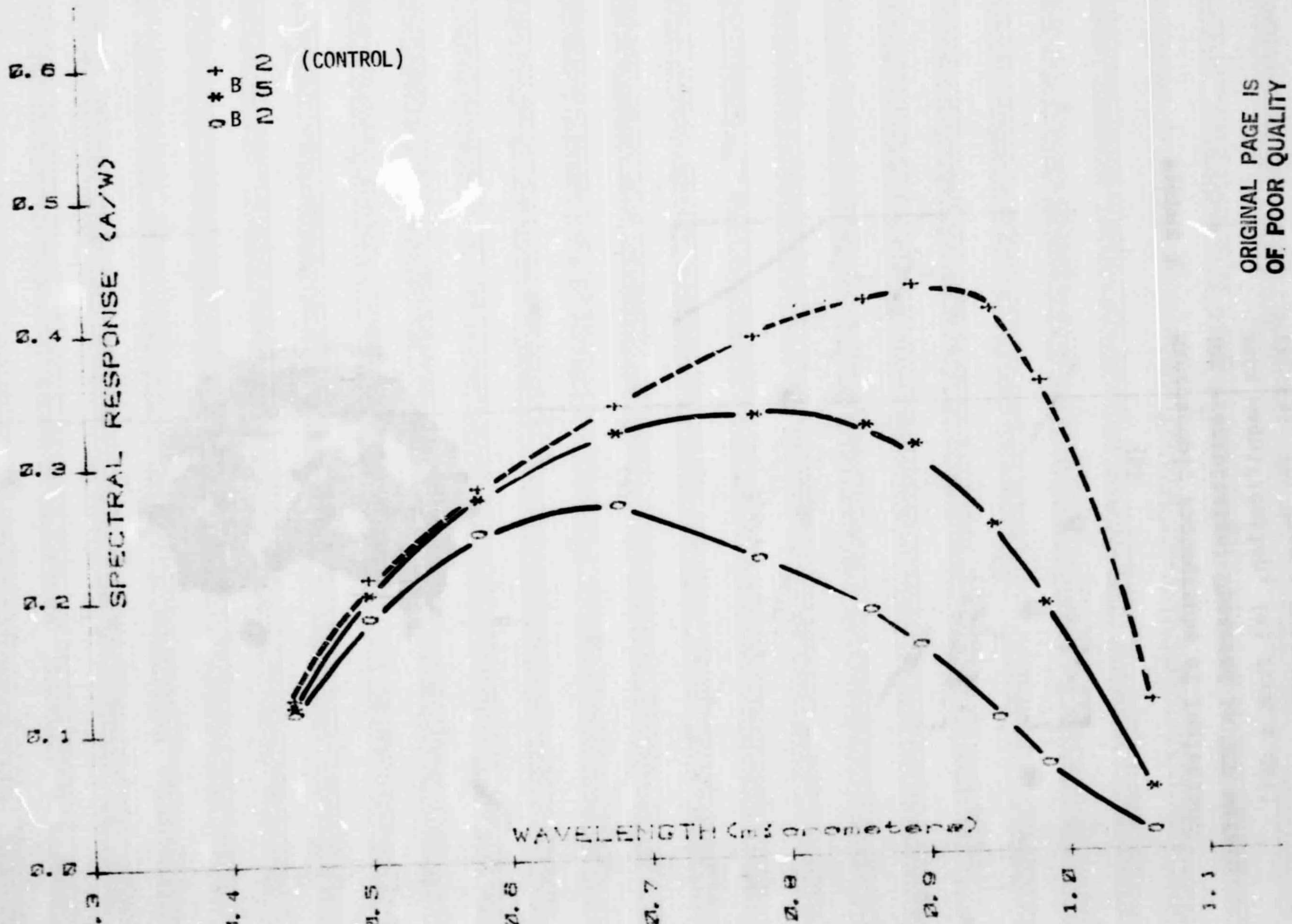
(a)



(b)

FIGURE 2. Microscopic Photographs of Inclusions (or Precipitates) Observed in UCP Wafers 200X Magnification, (a) From a Cell (#E-13), (b) From a Cell (#E5).

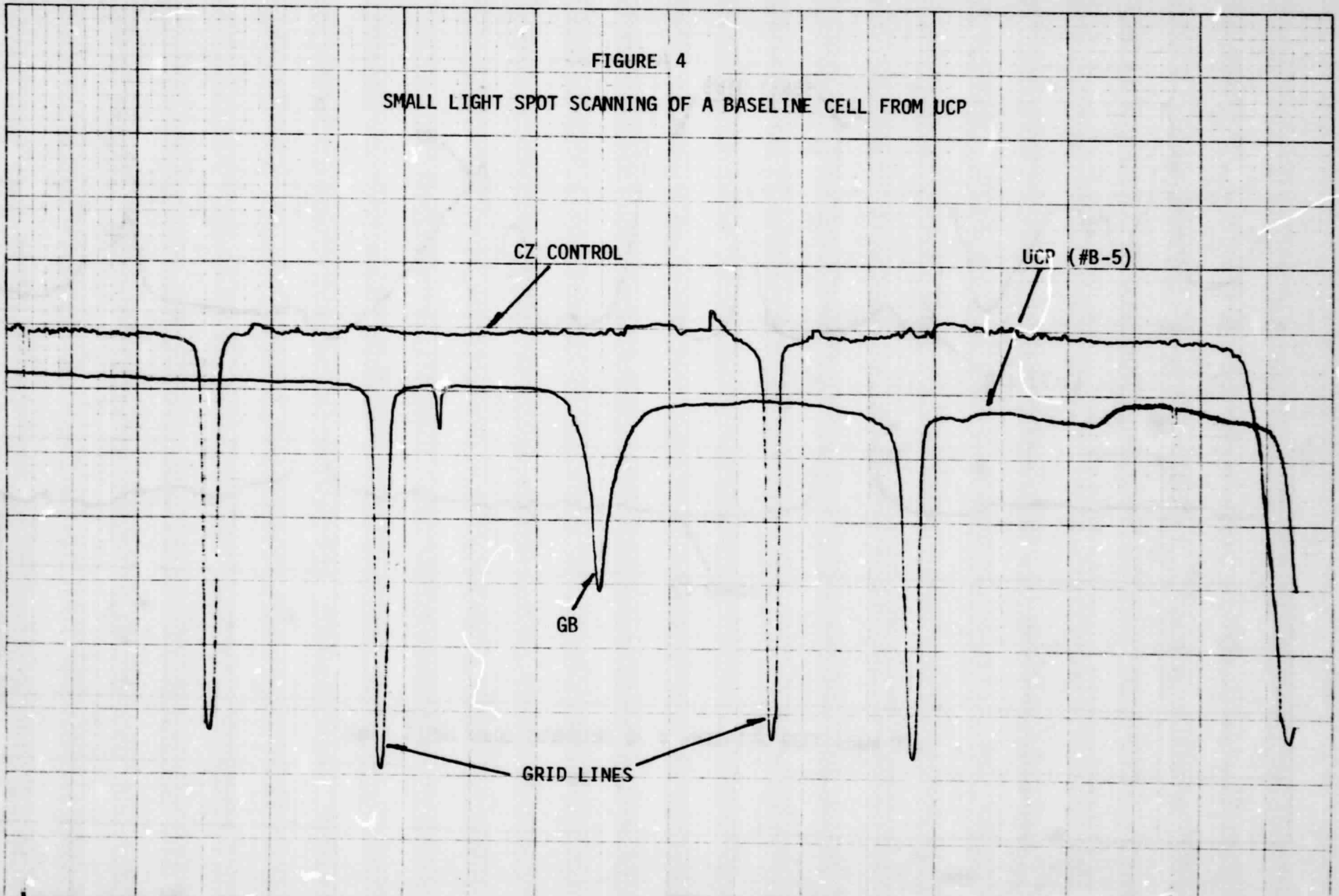
FIGURE 3. SPECTRAL RESPONSE OF BASELINE SOLAR CELLS (NO AR) FROM UCP



ORIGINAL PAGE IS OF POOR QUALITY

FIGURE 4

SMALL LIGHT SPOT SCANNING OF A BASELINE CELL FROM UCP



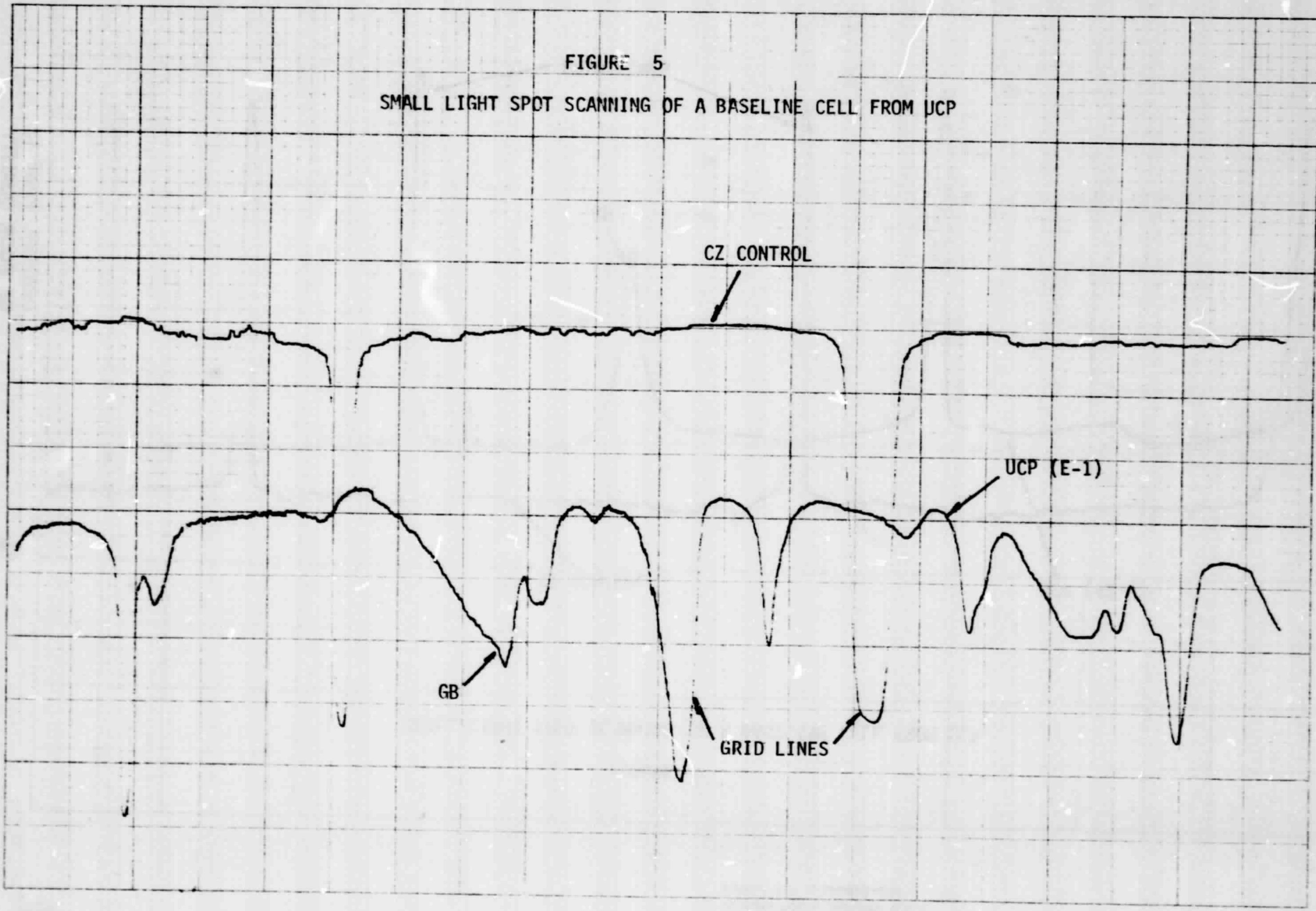
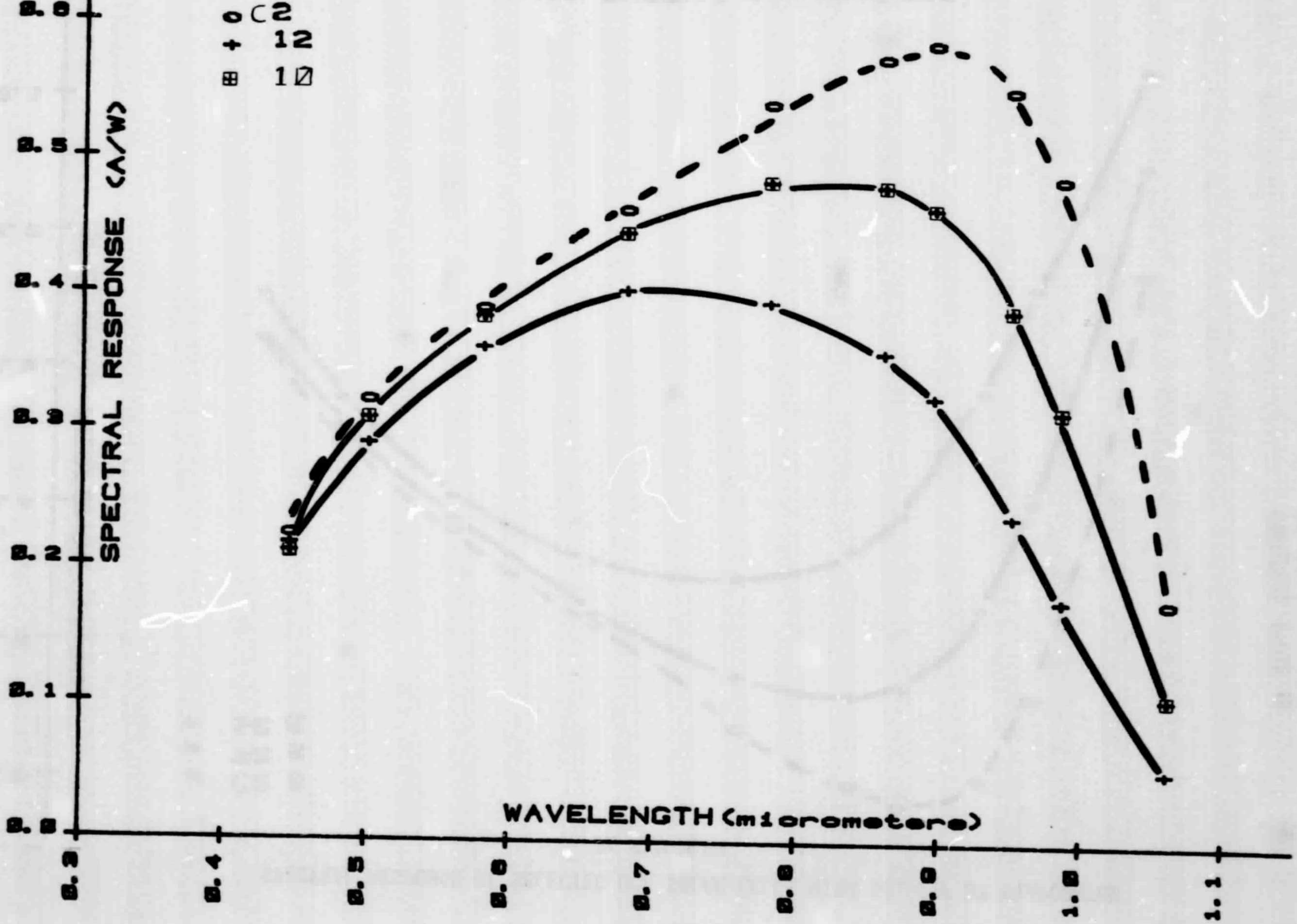


FIGURE 5

SMALL LIGHT SPOT SCANNING OF A BASELINE CELL FROM UCP

FIGURE 6

SPECTRAL RESPONSE OF SELECTED UCP SOLAR CELLS WITH SJ, BSR, (NO BSF) AND MLAR



ORIGINAL PAGE IS
OF POOR QUALITY

FIGURE 7

SPECTRAL RESPONSE OF SELECTED UCP SOLAR CELLS WITH SJ, BSF BY EVAPORATED AL AND MLAR

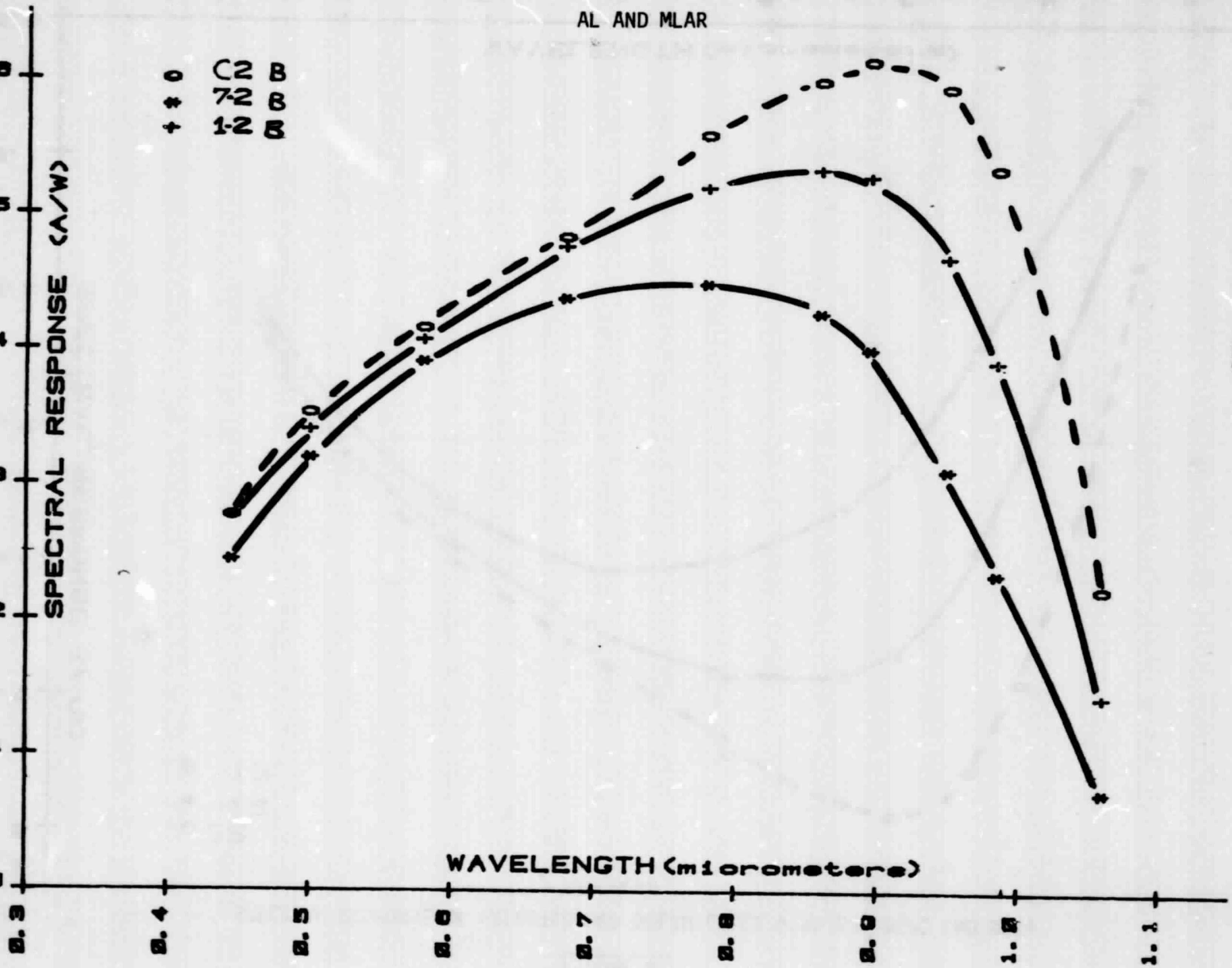


FIGURE 8

EBIC STUDY OF UCP MATERIAL

(a) EBIC PICTURE OF A 2x2 CELL ON UCP MATERIAL

(b) OPTICAL PICTURE ON THE SAME REGION OF (ENCLOSED AREA) OF A CORRESPONDING WAFER.

TABLE 1

SUMMARY OF RESULTS OF THE SOLAR CELLS FROM CAST INGOT BY UCP

WAFER #		Voc (mV)	Jsc (mA/cm^2)	CFF (%)	η (%)	NO.OF CELLS
A-5	Ave. S.D. Range	559 6 546-570	25.1 0.9 23.0-26.4	78 1 74-79	10.9 0.5 9.9-11.8	14
B-3	Ave. S.D. Range	554 9 540-568	25.1 1.2 23.1-26.9	76 2 70-79	10.6 0.7 9.6-12.0	15
C-1	Ave. S.D. Range	550 5 542-558	25.5 0.5 24.4-26.4	76 1 73-77	10.7 0.4 9.7-11.1	12
D-3	Ave. S.D. Range	557 8 542-568	26.0 0.7 25.0-26.8	76 2 70-78	11.0 .6 9.5-11.7	12
E-7	Ave. S.D. Range	543 14 504-558	25.4 0.6 24.0-26.1	72 10 44-78	9.9 1.5 5.5-11.2	12
F-3	Ave. S.D. Range	555 7 540-570	24.9 0.8 23.1-26.1	75 2 72-78	10.4 0.5 9.4-11.5	13
Combining All Wafers	Ave. Range	553 504-570	25.3 23.0-26.9	76 44-79	10.6 5.5-12.0	78
CZ Control	Ave. S.D. Range	586 - -	28.7 0.2 28.5-28.9	78 1 77-79	13.1 0.1 13.0-13.2	3

TABLE 2

EFFECTIVE MINORITY CARRIER DIFFUSION LENGTH OF SOLAR CELLS MADE FROM UCP WAFERS

	CELL NO.	L_D(um)	Jsc(mA/cm^2) (No AR)
GOOD CELLS	A-5-10	48	18.6
	B-3-5	72	19.2
	D-3-1	63	18.7
AVE.CELLS	A-5-15	44	17.6
	C-1-14	48	17.6
	E-7-1	46	17.6
BAD CELLS	A-5-12	28	16.3
	B-3-2	23	16.2
	F-3-6	37	16.3
	CONTROL #2	177	20.5

TABLE 3

SUMMARY OF GETTERING RESULTS

		Voc(mV)	Jsc(mA/cm^2)	CFF(%)	η (%)
D5	AVE. S.D. RANGE	557 7 546-564	25.8 .8 24.4-26.9	73 7 50-77	10.5 1.14 6.9-11.4
E5	AVE. S.D. RANGE	543.8 24.9 470-558	25.4 .7 23.6-26.4	67.7 12.7 31-76	9.4 2.0 3.6-10.8
T5	AVE. S.D. RANGE	554.6 16.9 498-570	25.0 .88 23.9-26.5	72 9 40-79	10.0 1.5 4.9-11.2
CZ CONTROL	AVE. S.D. RANGE	580 2.8 576-582	27.9 .46 27.4-28.5	75.5 2.1 73-78	12.2 .36 11.9-12.7

TABLE 4

SUMMARY OF UCP CELLS WITH SJ, BSF BY Al PASTE AND MLAR (1ST ATTEMPT)

		Voc (mV)	Jsc (mA/cm^2)	CFF (%)	(%)
D-1	AVE.	543	29.5	65	10.6
(7 Cells)	S.D.	15	.9	11	2.3
	RANGE	514-562	28.0-30.5	45-77	6.4-13.2

TABLE 5

SUMMARY OF UCP CELLS WITH SJ, BSF BY Al PASTE AND MLAR (2ND ATTEMPT)

CELL		Voc (mV)	Jsc (mA/cm^2)	CFF (%)	(%)
G-2 (15 Cells)	AVE.	526	26.7	64	9.0
	S.D.	9	0.7	9	1.4
	RANGE	510-544	25.9-27.8	47-74	6.7-11.5
H-2 (14 Cells)	AVE.	537	27.2	68	10.0
	S.D.	8	1.3	6	1.1
	RANGE	530-552	23.4	56-78	7.9-11.3
CZ Control (12 Cells)	AVE.	598	32.5	73	14.2
	S.D.	9	0.5	9	2.0
	RANGE	580-610	31.6-33.1	46-79	8.6-15.9

TABLE 6

SUMMARY OF UCP CELLS WITH SJ, BSR (NO BSF) AND MLAR

		Voc (mV)	Jsc (mA/cm^2)	CFF (%)	(%)
A-1 (14 Cells)	AVE.	567	27.6	77	12.0
	S.D.	5	.6	2	.5
	RANGE	554-574	26.3-28.9	73-78	11.1-12.6
CZ CONTROL (5 Cells)	AVE.	586	30.0	79	13.8
	S.D.	1	.2	1	.1
	RANGE	586-588	29.8-30.3	78-80	13.6-13.9

TABLE 7

UCP SOLAR CELLS WITH SJ, BSF

BY EVAPORATED Al, MLAR

		Voc (mV)	Jsc(mA/cm^2)	CFF (%)	(%)	BEST
UCP (12 Cells)	AVE.	572	29.5	78	13.2	
	S.D.	7	.9	1	.6	14.1%
	RANGE	560-584	23.2-31.1	77-80	12.4-14.1	
CZ CONTROL CELLS	AVE.	595	31.7	80	15.1	
	S.D.	1	.4	1	.2	15.4%
	RANGE	594-596	31.2-32.2	79-81	14.7-15.4	

TABLE 8

SUMMARY OF BASELINE UCP CELLS FROM THE

CORRESPONDING MATERIAL IN TABLE 5

CELL		Voc (mV)	Jsc (mA/cm^2)	CFF (%)	(%)
G-4 (16 Cells)	AVE.	543	24.8	75	10.0
	S.D.	7	1.1	3	.7
	RANGE	530-556	20.9-25.9	63-78	84-10.9
H-3 (15 Cells)	AVE.	546	24.9	75	10.2
	S.D.	5	.6	2	.4
	RANGE	538-552	24.0-26.0	70-77	9.6-10.8
CZ CONTROL (7 Cells)	AVE.	584	27.8	76	12.3
	S.D.	4	.2	3	.6
	RANGE	576-586	27.5-78.0	68-78	11.0-12.7

TABLE 9 +

SUMMARY OF LIGHT I-V DATA FOR 2 CM X 2 CM CELLS

FROM BRICK 4726(UCP MATERIAL)

BRICK LOCATION	CELL NUMBER 4726-	AM1 SHORT CURCUIT CURRENT DENSITY (MA/CM^2)	OPEN CIRCUIT VOLTAGE (VMV)	FILL FACTOR	AM1 CONVERSION EFFICIENCY (%)
TOP	A3-1	*	*	*	*
	A3-2	*	*	*	*
	A3-3	29	568	.73	12.0
	A3-4	30	564	.70	11.9
	A4-1	31	574	.65	11.5
	A4-2	30	543	.51	8.5
	A4-3	*	*	*	*
	A4-4	30	572	.76	12.8
MIDDLE	B3-1	28	542	.48	7.2
	B3-2	31	560	.57	9.8
	B3-3	25	561	.71	10.0
	B3-4	29	572	.66	10.9
	B4-1	30	574	.67	11.5
	B4-2	29	551	.48	7.8
	B4-3	30	577	.76	13.1
	B4-4	29	569	.72	11.9
BOTTOM	C3-1	19	486	.48	4.3
	C3-2	21	507	.48	5.2
	C3-3	18	513	.66	6.0
	C3-4	18	520	.72	6.7
	C4-1	19	525	.68	6.7
	C4-2	18	486	.52	4.4
	C4-3	18	515	.66	5.9
	C4-4	18	508	.65	5.9

+ It is a reproduction of Table 1.1 from Reference 4.

*Cells broken during processing

B. Solar Cells From LASS Process

1.0 Solar Cell Fabrication

The ribbons were made by the LASS process (Energy Materials). Advanced processed solar cells were fabricated from two ribbons. Because of the uneveness of the surface of this material, especially on the dendritic side, lapping was needed to prepare the samples and consequently some of the samples were very thin. BSR was applied to most of the samples while BSF was applied to a selected few. The yield was low on these cells mainly because of the thinness of many of the blanks. In the future, special thin cell processing will possibly be used with this material if necessary.

2.0 Solar Cell Performance and Characterization

Characteristics Under Illumination

Finished solar cells were tested under AM1 conditions at 28°C test block temperature. Table 9 lists the results of the cells. The only surviving BSF cell was shunted and was not included. The low Jsc of cells can be partially explained by lower active area, and the lack of a BSF, an essential for cells as thin as 5-6 mil.

Spectral Response

Absolute spectral response (A/W) was obtained using a filter wheel set-up. Response versus wavelength of selected cells are given in Figure 9. The blue response was relatively low, probably because of MLAR variations in different runs.

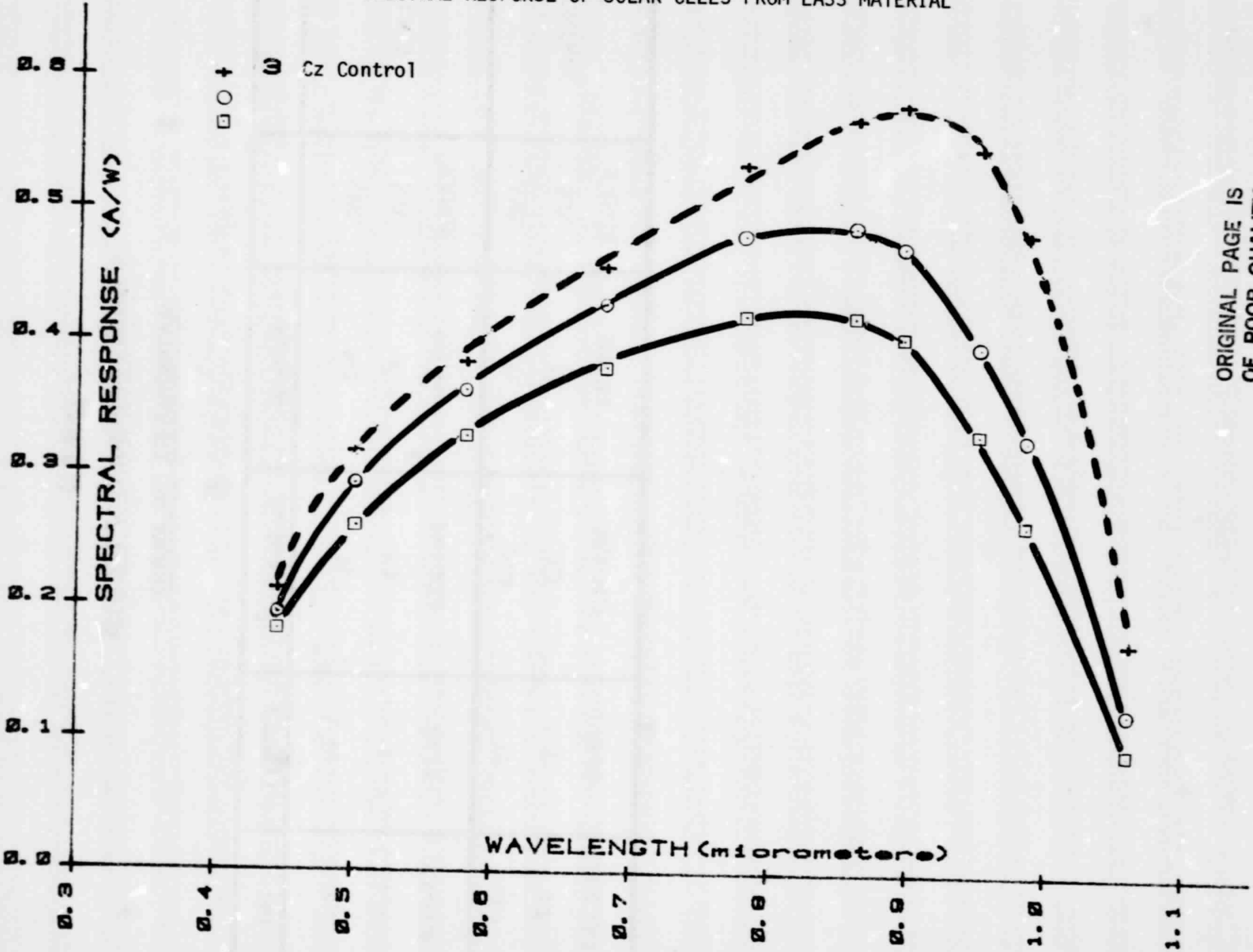
Minority Carrier Diffusion Length

Minority carrier diffusion length (L_D) for selected finished cells was measured by

the same filter wheel set-up using the short circuit current method (Reference 2). The results were listed in Table 10. The L_D values of the ribbons are fairly high for this material. The main problem was the scarcity of samples. this will be remedied in later tests, allowing a better evaluation of the true material quality.

FIGURE 9

SPECTRAL RESPONSE OF SOLAR CELLS FROM LASS MATERIAL



ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 10

SUMMARY OF RESULTS OF THE LASS MATERIALS (SJ, BSR, MLAR)

		Voc (mV)	Jsc (mA/cm^2)	CFF (%)	(%)
	AVE.	562	26	73	10.7
LASS	S.D.	9	1.3	5	1.16
	RANGE	552-574	24.1-27.4	65-77	9.4-11.8
	AVE.	581	30.8	75	13.4
CONTROL	S.D.	2	0.5	2	0.2
	RANGE	580-584	30.4-31.3	73-76	13.2-13.5

TABLE 11

EFFECTIVE MINORITY CARRIER DIFFUSION LENGTH OF SOLAR CELLS MADE FROM LASS MATERIAL

CELLS #	L_D (um)
1-2	76
1-4	76
2-4	85
Control CZ #3	167

III. CONCLUSIONS AND RECOMMENDATIONS

UCP

- From the initial wafers, gettering process proved to be unfruitful. For advanced processing, Al paste by BSF proved to have shunting problems while BSF by evaporated Al was reasonably effective and the best cell was 14.1%.
- EBIC study showed that most grain boundaries were electricaly active, but the overall effect of grain boundary on cell performance did not seem to be large.

LASS

- Due to the uneveness of the material, lapping was necessary and there was a severe yield problem. The efficiency of the cells averaged 10.7% with 13.4% on CZ control (advanced process without BSF).

The minority carrier diffusion lengths of the material were quite good, but the average Jsc was not as high as expected. This may be due to the irregular area of the final samples which reduced active area, and to the thinness of the sample. Since the number of cells were small, more work is needed for to determine the quality of the material as potential solar cell material.

Also, some attempt should be made to fabricate cells on the non-dendritic side of unlapped ribbons to see how they perform.

IV. WORK PLAN STATUS

The following silicon sheets are expected in processing and evaluation during the next period.

- o A UCP ingot will be sliced and studied to find out if any variation exists as a function of position.
- o More gettering tests will be performed on UCP silicon.

V REFERENCE

1. "Semi-Crystalline Casting Process Development and Verification", SEMIX Inc., Technical Reports, DOE Contracts No.DE-FCD1-80ET-23199.

2. H.I. Yoo et.al. "Silicon Solar Cell Process Development, Fabrication, and Analysis". JPL Contract No. 955089, Annual Report (Phase I), June 1979.

3. J.S. Culik and S. Katz, "Method to Monitor the Quality of Screen-Printed Aluminum Paste Back Surface Fields". Proceedings of 15th IEEE Photovoltaic Specialists Conference, p.512-517, 1981.

4. "Semi-Crystalline Casting Process Development and Verification", SEMIX Inc. DOE Contracts No. DE-FC01-80ET-23197, Quarterly Progress Report No. 2.

5. "Semi-Crystalline Casting Process Development and Verification", SEMIX Inc. DOE Contracts No. DE-FC01-80ET-23197, Quarterly Progress Report, No.3.

6. H.E Bates and D.N. Jewett "High Rate Growth of Silicon Ribbon by Low Angle Crystal Growth". Proceedings of the 15th IEEE Photovoltaic Specialists Conference, p.255-256, May 1981.

APPENDIX I

TIME SCHEDULE

TIME SCHEDULE

TASK	JUL	AUG	SEP
1. PROCESS SHEET SAMPLES			
a) Baseline Process			
b) Analysis			
c) Back-Up Measurements			
d) Test Alternate Process			
2. REPORTS			
a) Monthly		▲	▲
b) Quarterly			
c) Final			
3. INTEGRATION MEETING			

APPENDIX II

ABBREVIATIONS

V_{OC}:	Open Circuit Voltage
I_{SC}:	Short Circuit Current
J_{SC}:	Short Circuit Current Density
I_{SCR}:	Short Circuit Current (Red Response) at Wavelength Above .6um
I_{SCB}:	Short Circuit Current (Blue Response) at Wavelength Below .6um
CFF:	Curve Fill Factor
η:	Solar Cell Conversion Efficiency
L:	Minority Carrier Diffusion Length (D.L.)
I_{MAX}:	Current at Maximum Power Point
V_{MAX}:	Voltage at Maximum Power Point
BSF:	Back Surface Field
BSR:	Back Surface Reflector
V_B:	Bias Voltage
I_o:	Diode Saturation Current
HEM:	Heat Exchanger Method
EFG:	Edge Defined Film-Fed Growth
SOC:	Silicon on Ceramic
RTR:	Ribbon-to-Ribbon
UCP:	Ubiquitous Crystallization Process
SPV:	Surface Photovoltage
MLAR:	Multi-Layer Anti-Reflective
R_s:	Series Resistance

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX III

ELECTRICAL DATA SHEETS FOR UCP MATERIAL

CELL DESCRIPTION: Semix Solar cells (2x2 cm), Baseline Process with SiO AR coating

TEST CONDITION: AM 1

TEMPERATURE: 28°C Test Block, 6/81

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
Wafer	A-5					
1	556	24.9		78	10.7	3.85
2	556	24.4		79	10.7	4.00
3	560	25.5		77	11.0	"
4	570	26.1		78	11.5	"
5	562	25.9		77	11.2	"
6	556	26.1		78	11.4	2.32
7	552	24.5		76	10.3	4.0
10	564	26.4		77	11.5	"
11	556	24.9		77	10.6	"
12	546	23.0		79	9.9	"
13	560	24.3		79	10.8	2.02
14	566	25.6		78	11.8	4.00
15	560	25.0		78	11.0	"
16	558	25.0		74	10.3	"
Wafer	B-3					
1	546	24.4		76	10.1	4.00
2	540	23.5		77	9.8	"
3	552	24.7		75	10.2	2.71
5	568	26.9		79	12.0	4.00
6	550	25.4		76	10.7	"

CELL DESCRIPTION: Semix Solar Cells (2x2cm), Baseline Process with SnO AR Coating

TEST CONDITION: AM 1

TEMPERATURE: 28°C Test Block , 6/81

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
7	540	23.1		77	9.6	4.00
8	546	23.6		77	9.9	"
9	568	26.6		77	11.6	"
10	568	26.9		75	11.5	"
11	558	25.9		77	11.1	"
12	552	24.6		78	10.6	"
13	552	24.9		77	10.6	"
14	556	25.0		76	10.5	"
15	560	24.9		78	10.9	"
16	560	25.6		70	10.1	"
Wafer	C-1					
2	554	25.9		77	11.1	4.00
3	544	24.9		76	10.3	3.88
4	542	24.4		73	9.7	2.01
6	548	25.9		75	10.7	4.00
8	558	26.4		74	10.8	2.00
9	546	25.4		75	10.4	4.00
10	548	25.4		77	10.7	"
11	548	25.0		77	10.6	"
12	556	25.9		77	11.1	3.56

CELL DESCRIPTION: Semix Solar Cells (2×2 cm), Baseline Process with SiO AR coating

TEST CONDITION: AM 1

TEMPERATURE: 28°C Test Block, 6/81

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	η	AREA
	mV	mA/cm^2	mW	%	%	cm^2
14	552	25.5		77	10.9	4.00
15	552	25.6		75	10.7	3.16
16	554	25.5		77	10.9	4.00
Wafer	D-3					
1	564	26.4		75	11.1	4.00
2	562	26.1		78	11.5	"
3	550	25.0		76	10.4	"
4	544	25.0		76	10.3	"
5	558	26.6		77	11.3	"
7	542	25.1		70	9.5	"
9	562	26.4		77	11.4	"
10	560	26.8		76	11.4	3.45
12	560	26.0		77	11.2	4.00
13	568	26.6		78	11.7	"
15	556	25.9		78	11.2	"
16	554	25.6		77	10.8	"
Wafer	E-7					
1	544	24.9		76	10.3	4.00
3	558	25.9		78	11.2	"
4	552	25.5		77	10.8	"

CELL DESCRIPTION: Semix Solar Cells (2x2cm), Baseline Process with SiO AR coating

TEST CONDITION: AM1

TEMPERATURE: 28°C Test Block, 6/81

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
5	504	25.1		44	5.5	2.57
6	550	25.8		74	10.6	3.64
7	540	26.1		68	9.5	2.95
8	548	25.0		76	10.4	4.00
10	548	25.6		77	10.7	3.67
13	538	25.6		63	8.7	4.00
14	546	25.9		74	10.5	"
15	544	25.5		75	10.4	"
16	538	24.0		77	9.9	"
Wafer	F-3					
1	552	24.6		77	10.4	4.0
2	560	25.1		77	10.9	"
4	550	25.0		73	10.1	"
6	540	23.9		73	9.4	"
7	548	25.0		74	10.1	"
8	562	26.1		72	10.6	"
9	554	23.1		77	9.9	3.80
10	570	25.9		78	11.5	4.00
12	558	25.6		75	10.7	"
13	554	25.0		77	10.6	"

CELL DESCRIPTION: Semix Solar cells (2x2 cm), Baseline Process with SiO AR coating

TEST CONDITION: AM1

TEMPERATURE: 28°C Test Block 6/81

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
14	554	24.5		77	10.4	4.00
15	554	24.6		76	10.3	"
16	554	24.9		75	10.4	"
Cz	Control					
2	586	28.9		77	13.0	4.00
3	586	28.8		78	13.2	"
4	586	28.5		79	13.2	"

ORIGINAL PAGE IS
OF POOR QUALITY

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: SEMIX (GETTERING + BASELINE)

TEST CONDITION: AM1 SiO AR COATING

TEMPERATURE: $28^{o}C$

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
D 1	554	25.9		76	10.6	4.0
2	560	26.4		72	10.7	"
3	546	25.9		74	10.5	"
4	558	24.5		77	10.5	"
5	560	26.9		76	11.4	"
6	556	25.1		50	6.9	"
8	560	26.6		76	11.3	"
9	564	26.1		77	11.4	"
10	558	26.4		72	10.6	"
11	544	24.4		75	10.0	"
12	560	25.9		76	11.0	"
13	564	26.4		77	11.4	2.4
14	564	25.9		69	10.1	"
15	546	25.4		75	10.5	"
E 1	546	25.6		73	10.2	"
3	558	25.6		75	10.8	"
4	556	25.5		76	10.7	"
5	546	25.1		64	8.8	"
6	554	23.6		72	9.4	3.7

ORIGINAL PAGE IS
OF POOR QUALITY

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: SEMIX (GETTERING + BASELINE)

TEST CONDITION: AM1 SiO AR COATING

TEMPERATURE: 28°C

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
7	554	25.4		68	9.5	4.0
8	554	26.4		71	10.4	"
10	552	25.6		76	10.7	"
11	470	25.0		31	3.6	"
14	546	25.9		70	9.8	"
15	546	25.4		69	9.5	"
F1	498	24.4		40	4.9	4.0
2	558	26.5		70	10.4	"
3	552	24.4		76	10.3	"
4	558	25.0		76	10.6	"
5	548	23.9		66	8.7	"
6	542	23.7		74	9.5	1.6
7	554	24.6		77	10.5	"
8	568	26.1		76	11.2	"
9	560	25.0		76	10.6	"
10	568	26.1		73	10.7	"
11	570	25.9		76	11.2	"
12	562	25.4		77	11.0	"
13	558	23.9		79	10.6	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: SEMIX (GETTERING + BASELINE)

TEST CONDITION: AM1 SiO AR COATING
TEMPERATURE: 28°C

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
14	552	24.4		74	10.0	4.0
15	564	25.6		67	9.6	"
16	562	25.6		77	11.1	"
C 1	582	28.0		78	12.7	4.0
2	580	27.4		75	11.9	"
3	576	28.5		73	12.0	"
4	582	27.8		76	12.3	"

ORIGINAL PAGE IS
OF POOR QUALITY

CELL DESCRIPTION: Sem-x Solar Cells (Lot 1)
High Efficincy prosess with S.J., BSF, MLAR

TEST CONDITION: AM1

TEMPERATURE: 28°c Test Block - Temperature

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
Wafer D-1						
1	534	28.9		56	8.7	
2	546	29.9		72	11.7	
5	548	30.0		64	10.5	
6	548	30.0		70	11.6	
9	562	30.5		77	13.2	
10	550	29.5		75	12.2	
16	514	28.0		45	6.4	

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Semix Solar Cells (Lot 2)
High Efficiency process with Ag, BDF, TMXAR

TEST CONDITION: AM1

TEMPERATURE: 28°c Test Block - Temperature

NO.	V_{OC} mV	J_{SC} mA/cm²	P_{Max} mW	CFF %	η %	AREA cm²
Wafer G-2						
G-1	528	25.8		55	7.5	4.10
G-2	544	27.6		75	11.5	"
G-3	526	26.3		68	9.4	3.28
G-4	518	25.8		56	7.5	4.10
G-5	516	26.7		57	7.8	"
G-6	530	26.9		72	10.3	"
G-7	532	26.6		61	8.7	4.0
G-8	522	25.9		54	7.3	4.08
G-9	534	27.6		73	10.8	4.10
G-10	534	27.8		68	10.0	"
G-11	518	26.8		64	8.9	"
G-12	528	26.3		74	10.3	"
G-13	510	27.3		61	8.4	"
G-14	528	27.3		45	6.7	"
G-15	518	26.2		73	9.9	"
Wafer H-1						
H-2	544	28.1		66	10.2	3.75
H-3	524	26.2		69	9.5	"
H-4	534	23.4		63	7.9	"
H-5	546	28.8		71	11.1	3.61

ORIGINAL PAGE IS
OF POOR QUALITY

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Semix Solar Cells (Lot 2) High Efficiency process with S.J., BSF, MYAR

TEST CONDITION: AM1 DC

TEMPERATURE: 28°c Test Block - Temperature

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	n %	AREA cm^2
H-7	536	26.7		68	9.7	4.10
H-8	552	28.2		66	10.3	"
H-9	546	28.1		73	11.2	"
H-10	532	27.8		69	10.3	"
H-11	534	27.2		72	10.5	"
H-12	540	26.7		78	11.3	"
H-13	530	27.2		66	9.5	"
H-14	534	27.3		75	10.9	"
H-15	530	27.6		64	9.4	"
H-16	530	27.2		56	8.0	"
Cz Control C-1	590	32.4		63	12.0	4.10
C-2	590	32.0		72	13.7	"
C-3	598	31.6		76	14.4	"
C-4	596	32.0		77	14.7	"
C-5	580	32.0		46	8.6	"
C-6	594	32.6		76	14.6	"
C-7	602	33.1		74	14.8	"
C-8	610	32.9		78	15.7	"
C-9	600	32.9		77	15.2	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Semix Solar Cells (Lot 2)
High Efficiency process with DJ, BSF, MLAR

TEST CONDITION: AM1

TEMPERATURE: 28°C Test Block - Temperature

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	η	AREA
	mV	mA/cm^2	mW	%	%	cm^2
C-10	602	32.9		76	15.0	4.10
C-11	604	32.6		79	15.6	"
C-12	610	32.9		79	15.9	"

ORIGINAL PAGE IS
OF POOR QUALITY

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Sensy Solar Cells
Baseline (Reference for G & H high η cells lot 2)

TEST CONDITION: AM1

TEMPERATURE: 28°c Test Block - Temperature

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	n %	AREA cm^2
Wafer G-4						
G-1	534	24.1		74	9.5	4.0
G-2	544	25.1		74	10.1	"
G-3	544	25.0		74	10.0	"
G-4	550	24.9		78	10.7	"
G-5	538	25.1		75	10.1	"
G-6	542	25.1		74	10.0	"
G-7	530	25.0		63	8.4	"
G-8	556	25.6		76	10.8	"
G-9	542	24.9		75	10.2	"
G-10	544	20.9		77	8.7	3.49
G-11	544	25.5		74	10.3	4.0
G-12	556	25.5		77	10.9	"
G-13	540	25.1		75	10.1	"
G-14	546	25.9		75	10.6	"
G-15	534	24.5		77	10.0	"
G-16	544	25.0		76	10.3	"
Wafer H-4						
H-1	538	24.1		75	9.7	4.00
H-2	552	24.6		77	10.4	"
H-3	550	24.4		75	10.1	3.9

ORIGINAL PAGE IS
OF POOR QUALITY

CELL DESCRIPTION: Senex Solar Cells

TEST CONDITION: Baseline (Reference to G & H high η Cells: Lot 2)
AM1

TEMPERATURE: 28°c Test Block-Temperature

NO.	V_{OC} mV	J_{SC} mA/cm²	P_{Max} mW	CFF %	η %	AREA cm²
H-4	552	25.1		77	10.6	4.0
H-5	542	24.5		76	10.1	"
H-7	544	25.0		73	10.0	"
H-8	552	25.1		70	9.7	"
H-9	544	25.5		74	10.3	"
H-10	546	25.0		74	10.1	"
H-11	546	25.5		74	10.4	3.7
H-12	548	24.9		76	10.4	3.98
H-13	548	25.4		76	10.5	4.0
H-14	550	26.0		75	10.8	3.6
H-15	540	24.0		76	9.9	4.0
H-16	538	24.5		73	9.6	4.0
Cu Control C-1	584	27.8		76	12.3	4.0
C-2	586	27.8		78	12.7	"
C-3	576	28.0		68	11.0	"
C-4	586	27.8		77	12.5	"
C-5	584	27.5		77	12.4	"
C-7	584	28.0		77	12.6	"
C-8	586	28.0		77	12.6	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Semix Solar Cells
High Efficiency Process with SJ., BSR (No BSF) MLAR
TEST CONDITION: AM1
TEMPERATURE: 28°c Test Block Temperature

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
A-1-1	564	27.3		77	11.8	3.93
2	566	27.5		78	12.1	"
3	564	27.5		78	12.0	"
4	570	26.3		78	11.7	1.53
5	572	27.9		78	12.5	3.93
6	562	27.4		78	12.0	"
8	562	27.7		73	11.3	3.03
9	570	28.0		78	12.4	3.93
10	574	28.9		76	12.6	"
11	568	27.5		79	12.3	"
12	554	26.9		74	11.1	"
13	568	27.5		79	12.3	"
14	572	27.9		73	11.6	"
15	570	28.5		77	12.5	"
Cz 1	586	29.9		78	13.6	3.93
2	586	29.9		80	13.9	"
3	588	30.3		78	13.9	"
4	586	29.9		79	13.8	"
5	586	29.8		78	13.7	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Semix Solar Cells
High Efficiency Process with S.J, BSF by Evaporated Al, MLAR

TEST CONDITION: AM1

TEMPERATURE: 28°c Test Block Temperature

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	η	AREA
	mV	mA/cm^2	mW	%	%	cm^2
B-1-1A	560	28.7		77	12.4	3.97
1-1B	570	24.1		78	13.0	"
1-2A	576	29.6		78	13.3	"
1-2B	584	31.1		78	14.1	"
1-3A	574	29.6		77	13.1	"
1-3B	568	28.7		79	12.9	"
B-7-1A	574	30.0		77	13.2	"
7-1B	564	29.1		78	12.7	"
7-2A	568	28.7		80	13.0	"
7-2B	564	28.2		80	12.7	"
7-3A	582	30.5		79	14.1	"
7-3B	578	30.1		80	13.9	"
Cz-1A	596	31.6		80	15.1	3.97
2B	596	31.6		81	15.2	"
2A	596	32.2		80	15.4	"
2B	596	32.0		79	15.0	"
3A	594	31.5		80	14.9	"
3B	594	31.2		79	14.7	"

APPENDIX IV

ELECTRICAL DATA SHEETS FOR LASS MATERIAL

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: LASS Solar Cells
High Efficiency Process with SJ, BSR (No BSF), MLAR

TEST CONDITION: AM1

TEMPERATURE: 28°c Test Block Temperature

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	η	AREA
	mV	mA/cm^2	mW	%	%	cm^2
1-2	552	26.0		65	9.4	1.24
1-4	558	24.1		75	10.0	.964
2-3	564	26.5		77	11.5	1.572
2-4	574	27.4		75	11.8	1.847
Cz-1	584	31.3		73	13.4	4.00
2	580	30.4		75	13.2	4.00
3	580	30.8		76	13.5	4.00

ORIGINAL PAGE IS
OF POOR QUALITY